EFFECT OF CROP ROTATIONS SOIL QUALITY, PRODUCTION AND ECONOMIC RETURNS OF BARLEY GROWN UNDER ZERO TILL IN PARANA (BRAZIL)

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ABSTRACT

The cereal growing area of southern Brazil is characterized by high intensity rainstorms, warm temperatures, hilly topography, and acid soils low in natural fertility. Traditionally, cereals are grown in winter in a double cropping system with soybeans grown in summer. These factors combined with excessive use of disc-type implements causes severe soil loss by water erosion, low grain yields due to disease and insects, and general soil degradation. The combined use of zero or minimum tillage with crop rotations which include other crop types is one solution being examined with assistance from CIDA and involving scientists from Canada and Brazil. This paper reports on the agronomic and economic performance of 4 zero till barley rotations. After four years of study, the results show the beneficial effects of extending rotation lengths to break disease cycles as shown by improved barley yields. The choice of cropping sequence, however, significantly influences subsequent grain yields. While barley yields were highest for the 2-year and 4-year rotations and lowest for the barley-soybean rotation, net returns were generally highest for the 4-year and continuous barley systems. Soil properties such as organic matter, pH, and Al concentration did not change significantly with the use of extended rotations, however, the potential for soil erosion was reduced by use of zero tillage management.

INTRODUCTION

The Agriculture Canada Research Station at Swift Current, Saskatchewan, with funding from the Canadian International Development Agency (CIDA), is involved in a 5-year agricultural development project with the Centro Nacional de Pesquisa de Trigo (CNPT) at Passo Fundo, RS, Brazil. One of the objectives of this project is to assist CNPT staff in establishing research programs that address the very serious soil erosion and crop management problems that arise with traditional methods of wheat and barley production.

The traditional cereal growing area of southern Brazil is centered in the Parana, Santa Catarina, and Rio Grande do Sul. This area has a semitropical climate characterized by high intensity rainfall (1200-1800 mm) and warm temperatures. The topography is very hilly and the majority of the soils are acid, with high exchangeable aluminum, iron, and manganese, and low natural fertility, especially N, P, and K (de Sousa, 1984). Traditionally, winter cereals are grown in a double cropping system with soybeans, where the cereals are sown in May-June and harvested in October (winter season), and soybeans are sown in October-November and harvested the following April (summer season). The continuous use of a wheat-soybean or barley-soybean monoculture in combination with steep slopes, high intensity rain storms, and extensive use of disc-type implements for trash management and seedbed preparation causes severe soil loss due to water erosion, low winter crop yields due to disease build-up, and limited root penetration due to compaction of the subsoil and deterioration of soil structure (Kochhann 1988).

The use of zero tillage combined with cereal-soybean based rotations that include other crop types so as to break pathogen and pest cycles is being proposed as a management alternative which is expected to lead to improved grain yields and reduced soil erosion. The effects of 4 zero till barley rotations on grain yields, changes in soil quality, and economic returns are reported in this paper.

MATERIALS AND METHODS

The experiment was initiated in 1984 at Guarapuava, in south central Parana. The soil is a complex of Latosol Bruno Alico (Haplohumox) and Cambisol Alico (Haplumbrept) (EMBRAPA 1984) with initial characteristics as shown in Table 1. Before starting the study, the soil was conditioned as currently recommended for the establishment of zero till. According to these recommendations, the soil was subsoiled to 20 cm depth with a shank-type subsoiler, and 3.7 t ha-1 of lime plus 300 kg ha-1 of thermophosphate containing 18% P2O5, 9% Mg, and 20% Ca were broadcast and soil incorporated to 15 cm depth with a heavy-duty disc implement. Four rotation treatments: i) barley-soybean (continuous), ii) barley-soybean-vetch-corn (2-year), iii) barley-soybean-flax-soybean-vetch-corn (3-year), and iv) barley-soybean-flax-soybean-oats-soybean-vetch-corn (4-year) were established on plots, each measuring 6 m by 10 m, in a completely randomized block design with four replications. All stages of each rotation were present every season and each rotation was cycled on its assigned plots.

Table 1 Selected soil properties at the beginning of the study

Soil Property		Mean*	CV (%)
pH		5.07	3.42
Exchangeable Al	(meq 100 g^{-1})	0.89	41.36
Exchangeable Ca+Mg	(meq 100 g^{-1})	5.83	22.44
Available P	(ppm)	3.40	31.58
Available K	(ppm)	70.85	30.90
Organic Matter	(%)	6.68	3.73

* Means based on composite samples (40) taken from each experimental unit prior to the initial soil conditioning.

All crops were grown using zero tillage management. Herbicides, such as glyphosate or paraquat for winter cereal and soybean plots, and atrazine for corn plots, were applied as required and at recommended rates prior to planting for control of weeds and volunteer grains. All crops were sown in the standing stubble of the previous crop, without seedbed preparation, using a commercially available double disc planter, and using the currently recommended varieties at the rates of 90, 60, 50, 50, 90 and 15 kg ha-1 for barley, oats, flax, vetch, soybean, and corn, respectively. The barley seed was treated with a commercial fungicide and soybean seed was inoculated with an appropriate rhyzobium culture before planting. All plots received N, P, and K fertilizers based on current soil test recommendations (CNPT 1987). Barley plots received an average rate of 45 kg N ha-1, 89 kg P2O5 ha-1, and 48 kg K2O ha-1. Oats and flax received 33 kg N ha-1, 77 kg P2O5 ha-1, and 38 kg K2O ha-1, while soybean received 2, 57, and 41 kg ha-1 and corn 14, 64, and 66 kg ha-1 of the respective nutrients. Vetch was generally unfertilized. Most of the N and all of the P and K fertilizer was banded approximately 5 cm below the seed. The remaining N fertilizer was broadcast as a topdressing later in the growing season.

During the growing season, weeds were controlled using recommended herbicides and methods of application. The barley plots, particularly in the continuous rotation, also received fungicides at least once each year for control of fungal diseases. Yield was determined, for all crops except vetch, by threshing the entire plot using a plot harvester. Crop yields were corrected to 13% moisture content for barley, soybean, and corn, and to 10% moisture content for flax. The straw and crop residue was uniformly redistributed onto the original plots. During 1984 and 1985 the vetch was cut using a knife-roll; since then the vetch was desiccated by application of atrazine prior to the planting of corn.

Soil samples were taken to 18 cm depth immediately after harvesting the winter and summer crops. Six cores from each plot were taken and bulked to form a composite sample. The soil samples were analyzed for pH in water (1:1), P and K extracted with the Mehlich method, organic matter by wet combustion (Meilniczuk et al. 1971), Al+3 and Ca+2 + Mg+2 by titration of KCl extracts (Vettori 1969).

Daily weather data on precipitation and minimum and maximum air temperatures were recorded at a meteorological station located adjacent to the test site.

Assessment of the economic performance of the rotations was carried out using a partial budgeting approach. Net return was defined as the income above all variable costs plus depreciation and interest on machinery. In the analysis all inputs used in production and in field operations (e.g., seed, fertilizers, pesticides, labor, and machine operation and ownership) were valued at their May 1, 1989 cost levels for southern Brazil. Product prices were also initially fixed at their present levels of 300, 350, 350, 300, and 150 new cruzados t-1 (NCRZ$) for barley, flax, oats, soybean, and corn, respectively. In the analysis, product prices were varied from 75 to 125% of the base values to determine the sensitivity of the economic ranking of rotations to changes in relative prices. For the purposes of presentation, all costs and returns were converted to USA dollars assuming an exchange rate of 1 NCRZ$ = 0.5 USA dollars. No allowance was made in the analysis for costs associated with land ownership, improvements in soil erosion protection, or for changes in soil fertility due to differences in organic matter.

Crop yields, soil quality, and economic data collected in each season during the 1984-85 to 1987-88 period were subjected to analysis of variance (SAS Institute Inc. 1985) for a completely randomized block design with years, rotations, and replicates as factors. In the evident of significant rotation by year interaction, further analyses were conducted by individual year. Single degree of freedom comparisons were performed to test the hypothesis of no difference between means for each pair of rotation treatments.

RESULTS AND DISCUSSION

Weather Conditions

From 1984 to 1987, the area received an average of 1407 mm of annual precipitation. Roughly 66% of the rainfall was received in the summer, between November and April, and the balance was received from June to October. During the duration of the experiment, large variations in summer and winter precipitation were experienced, while heat units remained quite constant (Table 2). The distribution of precipitations within the growing seasons, rather than the amount of rainfall, has been identified as one of the most important constraints affecting cereal production in southern Brazil (Muzilli, 1984). In our study, for winter crops, growing season precipitation was greatest in 1984, but it was distributed most favorably, particularly during the critical heading stage, in 1987. Similarly, the summer of 1986-87 was characterized by normal precipitation, but it was poorly distributed, with short droughts at the beginning of the season which forced many producers to reseed soybeans (Terasawa, 1987). The summer of 1987-88 was also characterized by a prolonged drought towards the end of the growing season which affected the yields of late seeded and late maturing soybean cultivar.

Crop Yields

After four years of field study (one complete cycle of the longest rotation), the one year rotation (continuous barley-soybean) was characterized by significantly ($P<0.05$) lower barley yields than rotations that broke the monoculture system by including one or more years of a non-cereal crop sequence such as vetch-corn in the 2-year and 4-year rotations, or the flax-soybean-vetch-corn crop sequence used in the 3-year rotation (Table 3). No differences ($P>0.05$) in barley yields were observed among the rotations that broke the monoculture system with a non-cereal crop for more than one year. This indicates that the lower yields of barley in the continuous rotation are likely the result of high levels of plant pathogen inoculum survival on the barley residues during the soybean cropping season, while rotations that included one or more winter seasons without a cereal crop permitted death of pathogen inoculum as the barley residues decompose more completely in these systems (Fernandes, personal communication).

Table 2 Precipitation and heat units at Guarapuava.

	Winter Season Crop[1]		Summer Season Crop[2]	
Crop Year	Rainfall	Degree Days[3]	Rainfall	Degree Days
	(mm)		(mm)	
1984-85	596	1589	1011	2748
1985-86	381	1571	855	2851
1986-87	436	1509	1033	2704
1987-88	530	1504	822	2722

1. Includes period June 1 to October 31.
2. Includes period November 1 to April 30.
3. Calculated using a base temperature of 5 C.

Soybean yields were not affected by rotation length, but were significantly (P<0.0001) affected by years (Table 4), showing a continuous yield decrease with time, with an average yield loss rate of 387 kg ha-1 yr-1. This decline in yield may be the result of deterioration of soil physical conditions due to the lack of soil disturbance and also the result of the build up of pathogen inoculum in the crop residues of soybeans or other alternative hosts. Barley yields, although also affected by years (P<0.0001), did not show a trend with time, but reflected the weather conditions that prevailed during the growing seasons.

Table 3 Effect of rotations on barley and soybean yields.

	Mean Crop Yield[1]	
Rotation	Barley	Soybean
	--------($kg\ ha^{-1}$)------	
Continuous	2311[a]	2526[a]
2-Year	2594[b]	2612[a]
3-Year	2505[b]	2558[a]
4-Year	2579[b]	2553[a]

1. Means followed by the same letters are not significantly (P>0.05) different within crops according to Duncan's Multiple Range Test.

Yields of flax averaged 1004 kg ha-1 and were similar (P>0.05) whether grown in a 3-year or 4-year rotation. Oat yields averaged 2462 kg ha-1, and as for flax and barley were generally highest in 1987 and lowest in the 1986 winter season. Corn yields averaged 7454 kg ha-1 and were similar ($P>0.05$) for all mixed rotations.

Soil Quality

As expected, soil pH and exchangeable Al changed significantly ($P<0.0001$) as a result of the initial soil conditioning imposed to all the experimental units at the beginning of the study. Soil pH increased from 5.09 to 5.25 and exchangeable Al decreased from 0.89 to 0.25 meq/100g as result of liming. Soil organic matter (OM) decreased from 6.68 to 6.51 probably as surface soil was mixed with deeper layers and perhaps due to enhanced decomposition of plant residues after the initial tillage.

During the duration of the experiment, soil pH, exchangeable Al, and OM were affected by season, years, and by the crops grown within the seasons. Exchangeable Al and OM tended to be higher after summer crops, while pH tended to decrease after summer crops. Exchangeable Al, changed due to the effect of season itself ($P<0.0001$) and the effect of the crop grown within each season ($P<0.0002$), whereas pH and OM changed due to the effect of the crop grown within the season only ($P<0.0001$ and $P<0.0035$, respectively).

Table 4 Effect of length of cropping on barley and soybean yields.

Length of Cropping (Years)	Crop Yields[1]	
	Barley	Soybean
	--------(kg ha^{-1})-------	
1	2330[a]	3060[a]
2	2880[b]	2885[b]
3	2389[a]	2396[c]
4	3129[c]	1900[d]

1. Means followed by the same letters are not significantly ($P>0.05$) different within crops according to Duncan's Multiple Range Test.

The length of cropping after the initial conditioning treatment was important in determining the levels of pH, extractable Al, and OM. Thus, soil pH showed a trend to decrease significantly ($P<0.0001$) with time, and reached levels similar to those measured in the original soil only 4 years after liming

Table 6 Net returns by season and year for rotation treatments.1

	1984-85		1985-86		1986-87		1987-88		Mean		Mean2
Rotation	Win.	Sum.	Win.	Sum.	Win.	Sum.	Win.	Sum.	Win.	Sum.	Annual
	($ ha-1)										
Contin.	215^{a}	315^{b}	245^{a}	289^{a}	133^{a}	135^{c}	282^{a}	143^{c}	219^{a}	221^{c}	440^{a}
2-Year	92^{c}	354^{a}	116^{c}	329^{a}	58^{b}	300^{a}	113^{c}	214^{a}	95^{a}	299^{a}	394^{b}
3-Year	95^{c}	352^{a}	110^{c}	293^{a}	9^{b}	279^{ab}	110^{c}	180^{b}	81^{c}	276^{b}	357^{c}
4-Year	163^{b}	347^{ab}	167^{b}	289^{a}	25^{b}	254^{b}	220^{b}	174^{b}	144^{b}	266^{b}	410^{a}b

1. Rotations followed by the same letters within a season do not differ significantly ($P > 0.05$) according to Duncan's Multiple Range Test.

2. Winter plus summer season.

(Table 5). This is close to the period of time of time during which lime has residual effects on soils of southern Brazil (CNPT 1987), but indicates that under zero tillage the residual effect of lime in the soil may not last as long as under conventional tillage. Extractable Al showed a reverse trend as pH i.e. it increased significantly with time ($P<0.0004$), but unlike pH it did not reach concentrations close to the initial values. Soil OM on the other hand, although significantly affected by time ($P<0.0001$), did not follow a trend with time, but reflected the levels of crop production throughout the years.

Economic Returns

In contrast to barley yields, net returns for the winter season (at the base prices) were significantly higher ($P<0.05$) in all years for the continuous barley-soybean rotation, intermediate for the 4-year rotation, and generally lowest for the 2-year and 3-year rotations (Table 6). This reflects the higher proportion of land that was sown to the more profitable crop types (i.e., barley and oats) (Table 7). These results suggest that it was generally more profitable to produce barley in a monoculture system, even with its lower yields and greater expenditures for fungicides, compared to producing a mix of crop types; however, this ignores the level of market risk which may be lower as crop diversification increases. The low net return from flax production in most years reflects its generally low grain yield and poor market opportunities at present, while the low (or negative) net return for vetch reflects its use as a cover crop which produces no monetary income in the season it is grown. Unfortunately no measurements were taken in this study to evaluate the benefits of vetch in the succeeding crop, so as to estimate its economic benefit.

Table 5 Effect of length of cropping on selected soil properties.1

	Length of Cropping		
(Years)	pH	Exch. Al	O. Matter
		(meq 100g-1)	(%)
Initial	5.07	0.89	6.68
1	5.25[a]	0.25[a]36V	6.51[a]
2	5.17[b]	0.30[b]	6.72[b]
3	5.26[a]	0.32[bc]	6.56[a]
4	5.12[c]	0.36[c]	6.76[b]

1. Means followed by the same letters are not significantly different ($P>0.05$) according to Duncan's Multiple Range Test.

During the summer period, net returns were generally highest for the 2-year rotation and lowest for the continuous barley-soybean rotation (Table 6). This reflects the higher net returns that were earned from producing corn versus soybean under the present cost and price relationships (Table 7). The high net return from corn in this experiment is also due in part to the lower N fertilizer costs because of N fixation by the previous vetch crop compared to when corn is grown after a winter cereal. In most years the net returns from summer crops exceeded those earned from winter crops.

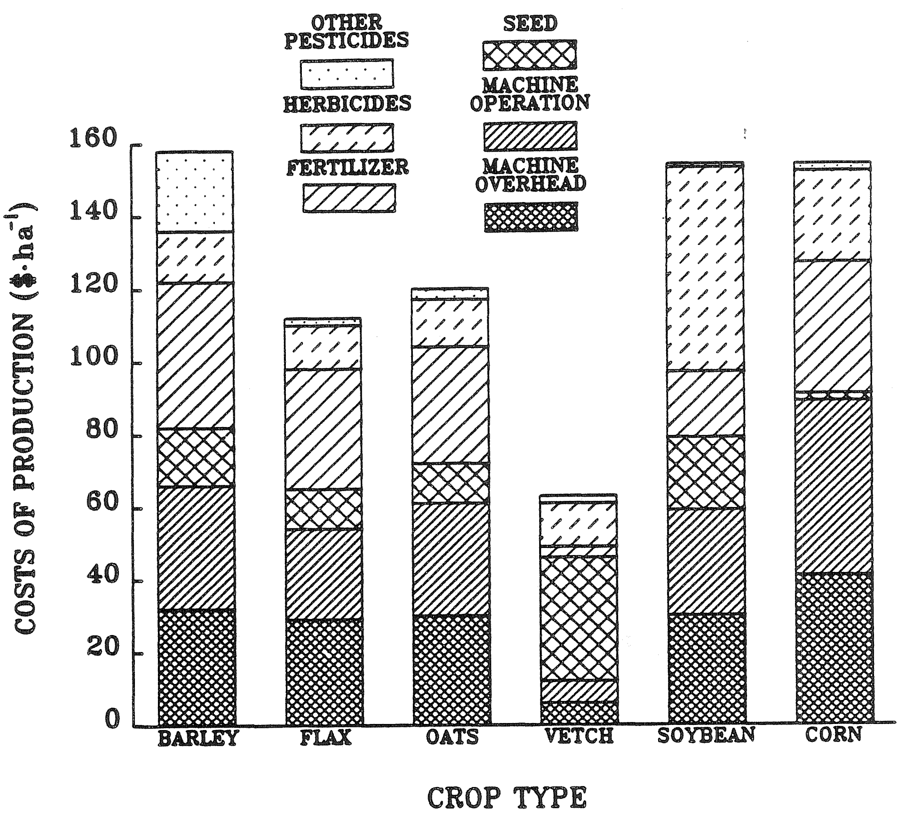

Figure 1 Costs of Production by Resource Category and Crop Type

When net returns were totaled over a crop-year (winter plus summer season), the continuous and 4-year rotations were generally the most profitable systems, while the 3-year rotation was generally the least profitable (Table 6). These results are in general agreement with those reported for conventionally tilled wheat rotations under study at CNPT (Zentner et al.

1989). This implies that although the mixed rotations offer the advantages of higher barley yields due to reduced disease and lower input costs because of savings in fertilizer and pesticides (Fig. 1), many producers will likely not find it economically attractive to adopt the mixed rotations under the present price structure, especially with the greater management skills and machine requirements of the mixed systems.

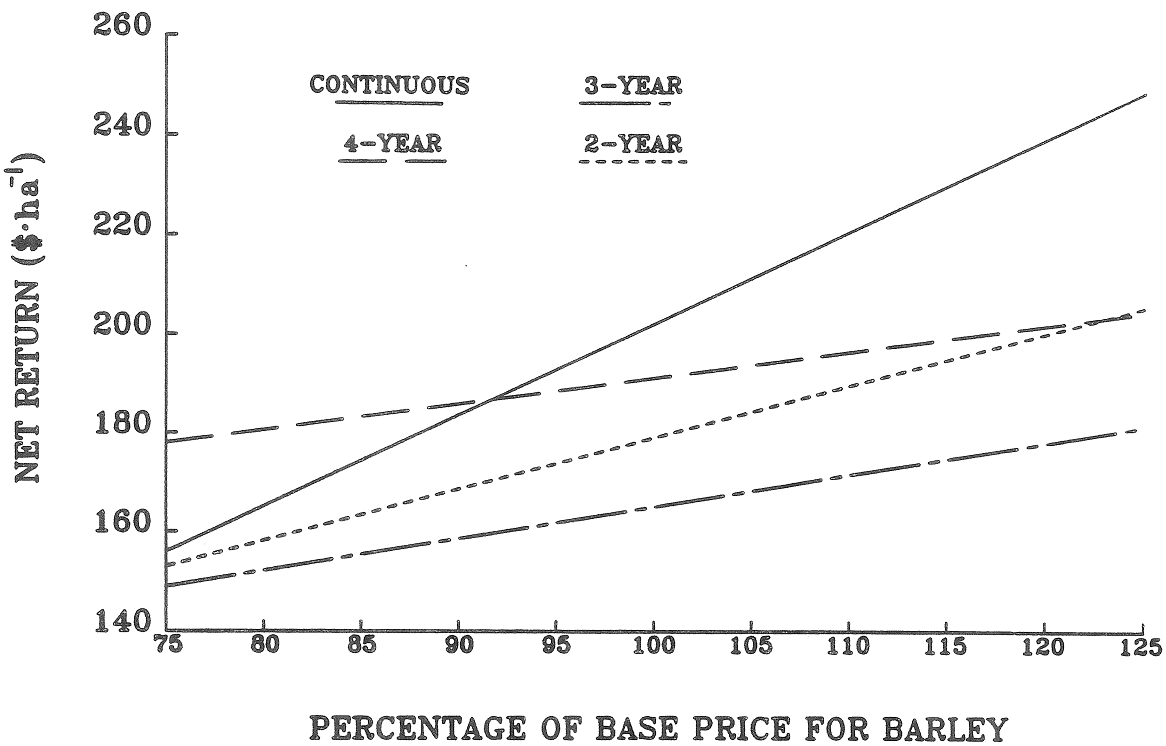

Figure 2 Effect of Changes in the Relative Price of Barley on Net Returns

Changes in the price of one product relative to another (or to a group of others) has a major impact on the economic ranking of rotations. An increase in the relative price for barley (all other product prices held constant) (Fig. 2) or for soybean (data not shown) increasingly favors use of the continuous barley-soybean rotation; however, a decrease in barley price to less than 90% of the base value (i.e., from 150 to less than 135 $ t-1) causes the 4-year rotation to become the most profitable system. Alternatively, if the price for soybean declined to less than 75% of the base value (from 150 to less than 110 \$ t-1), then the 4-year rotation would again become the most profitable system. Similarly, if flax price was increased by 35%, or oat price 20%, or corn price by 15%, then the 4-year mixed rotation would become significantly ($P<0.05$) more profitable than the monoculture barley system. However, substantially greater changes in relative product prices are required in order for the 2-year and 3-year systems to become more profitable than the continuous and 4-year rotations (data not shown).

Table 7 Net return by crop type.[1]

Crop Type	1984-85	1985-86	1986-87	1987-88	Mean
	($\$ha^{-1}$)				
Barley	234	277	163	299	243
Flax	119	74	-42	121	68
Vetch	-59	-46	-87	-69	-65
Oats	338	355	72	486	313
Soybean	327	286	139	143	224
Corn	392	328	482	269	368

1. Valued were averaged across all rotations with that crop type.

CONCLUSIONS

The four years of results from this ongoing study have shown that barley yields can be increased over that of the traditional barley-soybean system by incorporating other non-cereal crops in the rotation for at least one year. Analysis of economic returns, however, indicated that highest net returns were obtained with the barley-soybean and four-year rotations. Because in the barley-soybean monoculture system all the land in each season is dedicated to the production of a single commodity, this cropping system may be the most risky from both a production and market perspective. However, if the present economic policy of fixed prices for all commodities is maintained in Brazil, then the market risk factor is essentially removed.

Soil quality, as measured by pH and Al concentration, did not change significantly with use of the extended rotations, however, they showed a tendency to revert to their initial values with time.

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